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ABSTRACT

This paper discusses the implications of Piaget's theory to science education. The first section of the paper, "What Science Teachers Need To Know: Scientific Knowledge and Its Source," describes three sources of students' knowledge and corresponding educational practices. The second section, "Functions of Intelligence," discusses the concept of knowledge and provides a table comparing the traditional ideas, Piaget's science of knowledge, and its educational implications of eight functions of intelligence, including perception, learning, error, problems, imitation, language, imagery, and memory. The third section, "Conclusions," discusses the understanding of several Piagetian terms, teaching implications, and the goals of science education. The last section, "References," is an annotated bibliography on functions of intelligence, development of students' activity, developmental psychology, genetic epistemology, structures, education, and other works. A total of 42 references are listed. (YP)

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Oregon Department of Education
SCIENCE EDUCATION

# "Contributions of Piaget to Science Education"

SCIENCE CURRICULUM CONCEPT PAPER #2

## What Science Teachers Need to Know: Scientific Knowledge and Its Source

Like scientists, science educators need scientific knowledge regarding the objects and phenomena which are studied and understood in their disciplines. But science educators also need another science not needed by scientists. Science educators need scientific knowledge about *how students develop an understanding of scientific concepts* (Piaget, 1973b, pp. 21-23; 1970f, 166-173).

Educators' understanding of the development of scientific knowledge distinguishes science education as a profession and accounts for its very difficult nature. In short, science teachers must not only know scientific concepts; they must also understand how concepts develop in students' thought (Piaget, 1970f, pp. 123-133; 1973b, pp. 35-37).

There are three possible sources for concepts formed by human thought:

(a) concepts are formed and located outside the learner and are transmitted to the learner,

(b) concepts are hereditary intuitions and are expressions of innate capabilities to observe and generalize, or

(c) concepts are developed by constructive processes within the activity of the learner (Piaget, 1952, pp. 357-419; 1960, pp. 1-17; 1972, pp. 63-93).

**Three Views.** The three explanations of the source of students' knowledge lead to different educational practices:

(a) *External* -- If the source of scientific knowledge is thought to be *outside the learner,* then the teacher may become a giver of lectures, explainer, and organizer of demonstrations and hands-on experiences.

(b) *Internal* -- If the source of scientific knowledge is thought to be *inside the learner,* then the teacher may seek to use 'discovery methods' and draw upon the learner's innate capabilities or wait for them to develop.

(c) *Activity* -- If the source of scientific knowledge is thought to be in the *reorganization of activity to rebalance internal organizations with outside factors,* then the teacher may seek to work with students' mental activities, not simply performances, in order to develop the activities students attempt to initiate and adapt to reality (Piaget 1970f, pp. 25-29, pp. 137-180; 1973b, pp. 9-11, 92-109).

Piaget contributed a science of knowledge, genetic epistemology, which studies and explains the source of knowledge. Piaget's genetic epistemology focuses on the mechanisms which develop biological activity until it reaches the level of scientific thought. Genetic epistemology explains how human intelligence is a continuation of biological adaptation in which human activity makes contact with, and fits itself to, reality such that it comes to reflect reality in the precise manner of scientific knowledge (Piaget, 1960, pp. 14-17; 1970b, p. 12; 1972, pp. 19-20, 52-62).

# Functions of Intelligence

In research on the development of knowledge, Piaget's scientific findings of genetic epistemology show that knowledge is not a state or a thing which is stored or transmitted. Knowledge is mental activity which actively organizes and acts on reality and thereby also fits itself to it. Mental activity arises out of the continuation of behavioral activity by reconstruction and conceptualization in systems of mental activities (Piaget, 1973a, pp. 49-61; 1971a, pp. 1-7).

***Piaget's contribution was to change knowledge from a noun to a verb—knowledge is something students do, not something students have.***

The implication of Piaget's research for science education is that knowledge cannot be pre-organized and transmitted to students. Rather, knowledge must be developed through students' activity because teachers cannot transmit to students the coordination of mental activities into concepts nor do students have innate capabilities which allow immediate comprehension of meaning. Teachers verbal information can only trigger mental activity at the levels of organization which students have themselves developed (Piaget, 1973a, p. 119).

Traditional ideas of knowledge believe it to be a state formed prior to its presentation, a 'body of material' to be covered. These ideas lead to educational focus on how to present lessons, how to get and hold students' attention, at what level various concepts can be taught, what kind of activities best reinforce teaching, how to test to determine what material has been retained, and other concerns involved in the transmission of knowledge and its reception by students. Piaget's science of genetic epistemology raises different kinds of educational problems because knowledge is understood as arising from students' activity.

Table 1 summarizes some of the functions of intelligence Piaget studied to determine if knowledge is the product of a transmission and reception, if it is innate such as a basic ability to reason or observe, or if it develops from activity (what Piaget calls 'assimilation') (see *references* for citations).

## Table 1

| Topic and Problem | Traditional Idea | Piaget's Science of Knowledge | Implications of Piaget's Science of Knowledge |
|---|---|---|---|
| **1. Perception**<br>How does perception manage to produce apparent copies of reality? | Perception or observation is a direct impression or copy of reality received through the senses and therefore the most honest data we have of an object. | Perception depends on coordinations organized by sensory motor activities which shapes, determines, and corrects what is perceived. Perception in itself lacks objectivity. | Ask students to generate and organize demonstrations, models, visuals, and their observations. Do not present demonstrations, models, or visuals to transmit knowledge. |
| **2. Learning**<br>Does knowledge accumulate and develop from learning or does learning depend on development? | From generalization of many learning experiences, students form more abstract knowledge. Learning experiences produce development. | Learning only exercises existing methods of understanding. Development of understanding is produced by students' attempts to coordinate and organize activity and to work out its problems. | Make teaching focus on how learners organize a method, not on answers. Have students organize learning activities. Do not organize methods or completed knowledge for presentation to students. |

| *Contributions of Piaget to Science Education* | | | |
|---|---|---|---|
| **Topic and Problem** | **Traditional Idea** | **Piaget's Science of Knowledge** | **Implications of Piaget's Science of Knowledge** |
| **3. Contradictions/ Error**<br>What is the role of errors and misconceptions produced in students' work? | Errors indicate incorrect learning of skills or content presented by teacher or text. Monitoring and corrective feedback is necessary to prevent erroneous learning. | Errors aren't failures of learning but of understanding; they are reflections of students' methods of understanding and are needed by students to see results of their attempted method. | Let students produce and 'own' results of their activities. Feedback mechanism is presentation of method and results to peers which forces auto-correction. Errors are useful results. |
| **4. Problems**<br>What is the role of problems in promoting student growth? | Problems require practice and serve to re-enforce specific performance skill or concept application. Problems focus on producing correct answers or performances. | Growth depends not on practice of isolated skills and behaviors but on organizing activities into rational wholes or systems. Problems of method, not answer, are fundamental. | Pose problems of organization and method, not answer. Follow learning by helping students' see and pose problems raised by previous learning. Problems generate need for activity. |
| **5. Imitation**<br>What is the role of imitation and role models in producing student growth? | Modeling, demonstrating, and showing students how to solve problems or do a procedure provides students with a clear understanding of the knowledge or procedures. | The capability to imitate or learn from a model depends on students' organization of a method for reconstructing the models' activity. This development requires a construction by students. | Have students construct the model, the procedure, or the presentation. Don't present models or show procedures to imitate unless students have prior understanding. |
| **6. Language**<br>What is the role of language in knowledge? | Language contains and represents the logic and meaning of knowledge. By analyzing language used we can understand what it means; by learning language we can properly express thoughts. | Language does not store or transmit meaning nor does it create the representational function. Representational symbols are necessary to thought but do not form thought. | Develop understanding and meaning first in students; then provide labels for things. Do not focus on language training which does not create understanding; focus on developing students' meaning. |
| **7. Imagery**<br>What is the role of imagery in capturing and understanding reality? | An image is the perceptual copy of the object which remains when the object is absent. An image presents an object or shows a concept so that it can be understood. | Imagery is not a direct copy and does not derive from perception. It is constructed by mental activity and incapable of promoting or developing thought since it is a product of organizing function of mental activity. | Develop imagery by having students transform objects, perform transformations in thought, and capture in drawings or diagrams. Drawings/imagery depends on thought for its construction and representations. |
| **8. Memory**<br>How does memory work to conserve knowledge and experiences? | Information is received and encoded then stored in long or short term memory. All that is experienced is stored. The mind retrieves only partially what was placed in memory. | Memory is a reconstruction which depends on original organization of experience. Memory doesn't develop thought but is developed by thought. Memory reflects only what was understood. | Emphasize understanding over recall. Make all information available for learning and assessment. Stress active organizing of information and experiences, not storage. |

**Table 1: Comparison of traditional ideas, Piaget's science of genetic epistemology, and its educational implications (see annotated references for citations by category).**

The findings of genetic epistemology reveal that knowledge is not pre-organized outside learners nor is it transmitted to them through instruction, text, or from observation. The essential feature of knowledge is that it consists of the organization of activities which act on reality to modify it and therefore to know it (Piaget, 1970b, p. 15; 1973a, pp. 90, 107). Thus, external factors can support and provide stimulus for the mental activities of students but the essential work of organizing, coordinating, and fitting these activities of thought to reality can only be done by students (Piaget, 1957, p. 39; 1960, pp. 34-50; 1970b, pp. 14-16).

The fundamental switch from traditional ideas of knowledge to knowledge as systems of mental activity changes the nature of the problems, roles, and needs of science teachers. The shift from instruction which attempts to transmit completed knowledge to instruction which attempts to see and work with the systems of mental activity students naturally and actually generate, changes the nature of problems and roles of various instructional functions (Piaget, 1973b, pp. 1-37).

The source of knowledge for students does not fundamentally lie with the teacher, direct experience with objects, language, demonstrations, or visuals; the source of knowledge lies within students' organization of activity. To know does not mean to receive impressions and data from which to generalize. To know means to mentally act on the object and thereby to reconstruct the object in thought (Piaget, 1970f, pp. 10-20).

# Conclusions

## Understanding

If educators wish to understand and use Piaget's research showing knowledge as mental activity organized by students into systems, several important needs arise:

1. *Systems* -- Science educators will need clear, technical specifications and understanding of the fundamental nature and properties of systems as they are found in student activities at all levels. The understanding of systems as logico-mathematical models of thought provides a precise language for describing mental operations. Piaget found three major systems by which thought organizes its activities:
   - functional or one-way (non-reversible) systems,
   - operational or two-way (reversible) systems, and
   - formal operational or four-way (doubly reversible) (Piaget, 1957, pp. 8-37; Piaget 1970e, pp. 3-16; Piaget & Inhelder, 1969, pp. 92-151).
2. *Functions and Structures* -- Science educators will need precise descriptions which clearly distinguish both the functions (the 'why' expressed in Piaget's assimilation and equilibration theory) and the structures (the 'how' addressed in the functional, concrete operational, and formal operation systems) of the development of students' understanding of each key concept and the overall structure of the discipline (the basic conceptual organizers and the 'model' which relates them one to another) (Piaget, 1971A, pp. 138-185.

(a) *Functions remain constant* (what Piaget calls the 'functional invariants', the equilibration of assimilation and accommodation) (Piaget, 1952, pp 1-20) through investigation cycles. These functions include:

- finding and identifying problems,
- generating ideas and hypotheses,
- formulating methods,
- gathering data and conducting verifications,
- analyzing the results and evaluating progress, etc. (for a complete assimilation model see Piaget, 1977, 3-77).

(b) *Structures or systems of understanding change and develop* through investigation cycles. These structures include:

- *first preoperational methods*, pre-concepts, unstable (perceptual) data, definitions by

usage, non-logical analysis, etc.

- *then operational methods*, concepts, objective description, conceptual definitions, deductions, etc.
- *and finally, formal operational methods*, hypotheses organizing and isolating all possible variables, propositional logics, true experimental methods, explanations, etc. (Piaget, 1970d, pp. 74-76 ).

3. *Problems of Development* -- Science educators will need an identification of the key problems which student thinking must overcome at each stage in their development of understanding of a phenomenon. And, these problems should be related to the usefulness each discipline has in solving fundamental human problems of adaptation since knowledge is itself an expression of the adaptation of thought to reality (Piaget, 1960, pp. 7-17).
   - For example, problems of classification and description form initial Stage I problems producing laws and facts which allow simple predictions and generalizations.
   - As understanding advances to Stage II, the problems of description and conceptualization shift to deeper problems of relationships which allow the deduction of laws and the formulation of logical or mathematical systems.
   - Finally, in Stage III, problems of explanation arise from the natural progression to attempt to understand and find the reason for things which allows the construction of a causal model (Piaget, 1970d, pp. 73-76; 1972, pp. 20-51, 78-81).
4. *Psychological Facts* -- Science educators will need factual descriptions of what the actual systems of mental operations will look like at each stage of development (Piaget, 1973b, pp. 21-23). When student investigation begins, teachers must have a clear idea of:
   - what to expect from students,
   - how to differentiate between learning or socialization effects in students' behavior, and their systems of understanding and conception, and
   - clear examples of how students reason and organize their activity at each stage of development.

   These psychological facts will assist teachers in determining exactly what a concept means to students at every level of development (see texts listed in reference section for many descriptions of students' activity).
5. *Factors of Development* -- Science educators will need knowledge of the role various factors play in the development of students' knowledge. To make student development rather than simple learning the goal of education, the intellectual functions used in learning cannot be taken for granted. Information about the development of functions and their role in student cognitive development will need to be made available to teachers. These functions include:
   - memory,
   - language,
   - teacher explanation,
   - pre-organized laboratory activities,
   - student analysis and reflection,
   - social interaction and cooperative learning,
   - textbooks,
   - experiments organized and performed on objects, etc.

   Science educators will need precise understanding of the proper roles of the various functions in promoting the development of student understanding (Piaget 1971c, 45-67; 1976, 332-353).

## Teaching Applications

Piaget's scientific understanding of the knowledge of the science curriculum, which allows educators to see and work with the development of students' systems of mental activity, leads to a need for new techniques and methods of teaching.

1. *Student Research Problems* -- Science teachers will need effective activities and methods which help students find and formulate problems of investigation which are specially fitted to helping students develop understanding of the concepts of the curriculum. These have to do with specific techniques for getting student activity started and working with what students initiate to help them find an interesting, clear, and purposeful direction for their learning activities.

2. *Methods of Investigation* -- Science teachers will need methods and materials which allow them to work with students' activity as it develops rather than with presenting knowledge. These must assist and develop in students their ability to organize their learning activities. Development occurs when many learning activities form cycles so as to successively build on previous learning and follow the natural development of a system of understanding.

3. *Data and Learning Results* -- Science teachers will need rich data sources for students' use both in the form of actual objects and phenomena, and in representational sources (written and visual). Science teachers will need corresponding methods and strategies which make effective use of student learning activity. Instead of carefully organized textbooks and laboratory procedures, instructional methods featuring student development require that students organize investigations and previous learnings into coherent understandings and explanations.

4. *Qualitative Assessments* -- Science teachers will need qualitative methods which help students display their own development of understanding so as to establish student feedback mechanisms within the classroom. Institutional methods of assessment and evaluation must provide the objective description and explanation of the development of students' systems of understanding as seen in the actual products of learning activities. These assessment methods must be clearly distinguished from students' own interests in self-evaluation and self corrections.

Thus educational practice and understanding can be expected to follow the same fundamental path of all practical activity and cognitive development. It begins with an initial awareness and ability to see only outward, observable appearances or end results, and progresses toward increasingly understanding the internal processes, methods of production, and developmental mechanisms of mental activities (Piaget, 1976, 335-337).

For educational practice, this law of development suggests that the traditional teaching focus on observable student behaviors and performances will gradually give way to instructional focus on the internal mechanisms of thought and finally to their development. Corresponding to this development will be techniques which increasingly take account of and work directly with the actual systems of mental activity students can initiate and organize in response to problems they see and address (Piaget, 1970f, 170-173).

## Goals of Education

The real problem set before educators is the nature of intellectual development which education intends to produce in the future citizens of society. Does science education attempt to stock the memory and prepare citizens who follow the directions, constructions, and completed understanding of others, or does science education intend to actively pursue the intellectual development of every student so as to prepare citizens who can solve problems, who can organize and invent, who can make sense of difficult situations and organize methods of action, and in short, who have constructed an understanding such that "they are capable of production and creativity and not simply repetition?" (Piaget, 1970f; pp. 17-20; 1973b, pp. 3-37)

> ***"The goal of intellectual education is not to know how to repeat or retain ready-made truths (a truth that is parroted is only a half-truth). It is learning to master the truth by oneself at the risk of losing a lot of time and of going through all the roundabout ways that are inherent in real activity" (Piaget, 1973b, p. 106).***

The ideal for science education is to increasingly understand and affect the fundamental intellectual development of students. This supposes the movement away from traditional, transmission methods of teaching which

appeal to the illusion that knowledge can be presented and transmitted ready made to students.

It is true traditional methods produce immediate performance effects in students. However, it is the intellectual development of students which has the long range effect of promoting understanding and counts for most. Piaget's science of knowledge provides both a scientific basis for science educators who wish to understand student development and an ideal for attempts to fashion educational methods which ***"organize situations that create useful problems for students and discussion which creates the need for reflection and reconsideration...What is desired is that the teacher cease being a lecturer, satisfied with transmitting ready-made solutions; his role should rather be that of a mentor stimulating initiative and research...This obviously leads to placing all educational stress on the spontaneous aspects of students' activity" (Piaget, 1973, pp. 11, 16).***

# References

(An asterisk indicates a cited work. Numbers correspond to numbers in Table 1. Some texts appear twice.)


**1. PERCEPTION:**

1969a. Piaget, Jean. ***Mechanism of Perception.*** Translated by Gavin Nott Seagrim. New York: Basic Books. Provides a summary of the technical research showing how intelligence provides the necessary organizing relations out of perceptual stimuli to create a perceptual 'field' or whole. Perception is not static and distinct from the operational compositions of intelligence nor is perception the source of knowledge since perception always depends on intelligence for the construction of the whole as perceived. Direct perception is often highly distorted and misleading since it is uncorrected appearance. Final three chapters provide an excellent summary and conclusions.

**2. LEARNING:**

1974. Inhelder, Bärbel; Sinclair, Hermine; and Bovet, Magali. ***Learning and the Development of Cognition.*** Translated by Susan Wedgwood. Cambridge: Harvard University Press. Directly addresses the problem of how understanding develops, whether fundamentally dependent on learning or on development (the latter is the case). Also shows the integrated nature of the development of understanding since concepts interact in a complex manner (e.g., measurement is not simply the application of number but forms a parallel and interactive development of its own).

**3. CONTRADICTIONS/ERRORS:**

1980a. Piaget, Jean. ***Experiments in Contradiction.*** Translated by Derek Coltman. Chicago: University of Chicago Press. Since it is disequilibrium which drives development, it is easy to assume contradictions are the source of development. This research text shows that contradiction is not the source of disequilibrium nor of development but that the capability to see a contradiction itself depends on the development of a system of logic.

**4. PROBLEMS:**

*1976. Piaget, Jean. ***Grasp of Consciousness.*** Translated by Susan Wedgwood. Cambridge: Harvard University Press. Addresses when and how awareness takes place. Shows conscious awareness of problems and their solutions involves a construction and is a reconstruction of activity in thought. Awareness is thus not a simple illumination of activity but involves a development of its own, beginning with the most peripheral appearances and proceeding to 'seeing' the 'how' which produces the outward appearances.

1978. _____. ***Success and Understanding.*** Translated by Arnold J. Pomerans. London: Routledge & Kegan Paul. Addresses the relationship between overcoming problems of technique (know how) leading to practical activity (success), and understanding activity in thought. Shows how the reconstruction of activity as thought may initially lag behind successful action and even misrepresent action, while later, thought far outstrips action.

## 5. Imitation, 6. Language, and 7. Imagery:

*1973a. Piaget, Jean. ***Child and Reality: Problems of Genetic Psychology.*** Translated by Arnold Rosin. New York: Grossman. Chapter 6 shows that language does not contain or even completely reflect the rational systems of thought or meaning of which it forms the representational aspect. Language depends on the formation of meaning and therefore the coordination of mental activity but does not itself provide the coordinations of rational thought. Language is only the figurative aspect of thought and does not compose the operative aspect.

1967. _____. ***Six Psychological Studies.*** Translated by David Elkind and Anita Tenzer. New York: Random House. Chapter 3 describes the development of language and its relationship to thought. Thought precedes language. Language confines itself to helping thought by providing it with its representations thus allowing its evocation of absent situations initially through imitations, symbols, and finally language itself.

1971. Piaget, Jean, and Inhelder, Bärbel. ***Mental Imagery in the Child: A Study of the Development of Imaginal Representation.*** Translated by P. A. Chilton. New York: Basic Books. Reports research which shows the active nature of intelligence in constructing images and refutes the notion that the image is simply a copy of the object. What we 'see' as reality actually consists of a construction organized by a system of transformations developed by intelligence.

*1969. _____. ***Psychology of the Child.*** Translated by Helen Weaver. New York: Basic Books. Chapter 3 presents the "semiotic or symbolic function" to show its development from deferred imitation which starts after the disappearance of the model, to symbolic play, to graphic images, to mental image, and finally to verbal evocation of events which are not occurring at the time. The role of language is only to detach thought from behavioral action by its representation and not to develop meaning and thought.

## 8. Memory:

1973. Piaget, Jean, and Inhelder, Bärbel. ***Memory and Intelligence.*** Translated by Arnold J. Pomerans. New York: Basic Books. This research text shows how memory, far from being simply a placement into long or short term storage, is actually a reconstruction of experience by the use of organization provided by intelligence. Thus, we remember what we understand. The development of intelligence enriches the powers of memory even with no intervening experiences while at early stages what is remembered may actually be erroneous.

## The Development of Students' Activity:

The following research texts all show how activity develops at the sensory motor level to be reconstructed on the plane of thought as the basic concepts of space, time, object, movement, and so forth. In each instance the concepts recapitulate the formation of a system of operations having the same analogous forms as logic does in its classification (concepts) and seriation (relations) systems.

1958. Inhelder, Bärbel and Piaget, Jean. ***Growth of Logical Thinking From Childhood To Adolescence: An Essay on the Construction of Formal Operational Structures.*** Translated by Anne Parsons and Stanley Milgram. Basic Books. An essential research text for science educators. Shows and explains the basic laws of development as thought organizes its operations into conceptual systems and then reconstructs the conceptual systems as 'variables' organized by a far richer, formal, hypothetical deductive logic.

1964. _____. ***Early Growth of Logic in the Child: Classification and Seriation.*** Translated by Eric A. Lunzer and D. Papert. New York: Harper & Row. A classic, essential research text describing the fundamental principles of concept and relation formation in students. There is perhaps no social scientific phenomena more stable and fundamental than students' classification systems displayed in these studies.

1970a. Piaget, Jean. ***The Child's Conception of Movement and Speed.*** Translated by G.E.T. Holloway and M.J. MacKenzie. Basic Books. Presents the development of concepts of movement and speed from their origins in displacement actions of objects.

1969b. _____. ***The Child's Conception of Time.*** Translated by Arnold J. Pomerans. Basic Books. Repeats the pattern of Piaget's classic conservation studies to show the conservation of time as a concept which is developed by students' mental activity. Shows temporal systems (durations and order of events) are analogous to classification and seriation.

*1977. _____. ***Development of Thought: Equilibration of Cognitive Structures.*** Studies in Genetic Epistemology, vol. 33. Translated by Arnold Rosin. New York: Viking Press. Provides the explanation of the development of thought as the equilibration of the various functions found within mental activity. If knowledge does not come from learning experiences, language transmissions, biological maturation of innate capabilities, then the fundamental developmental factor lies within the self-regulating qualities of living activity, that of the equilibration of the forms of activities the organism generates and the modifications of those forms by the external reality which the activity assimilates.

*1952. _____. ***Origins of Intelligence in Children***. Translated by Margaret Cook. New York: International Universities Press, Inc. Lays out the fundamental theories of the formation of sensory motor intelligence and the mechanism of mental assimilation. The introduction is particularly important in defining the question of the relationship between mind and biological organization. Any theory of intelligence must explain how biological functioning is able to eventually produce the systems of intelligent thought which forms the mind.

1974. Piaget, Jean, and Garcia, Rolando. ***Understanding Causality.*** Studies in Genetic Epistemology, vol. 26. Translated by Donald and Marguerite Miles. New York: W.W. Norton & Co. A rich source for the study of students' developing conceptions of all sorts of phenomena—heat, light, sound, energy, work, transmission of forces, vectors of forces, changes in states of matter, etc. These studies describe the development of students' understanding to arrive at causal explanations as an invariance through transformations of objects. Must reading for every science educator.

1977. Piaget, Jean; Grize, Blaise; Szeminska, Alina; and Bang, Vinh. ***Epistemology and Psychology of Functions***. Studies in Genetic Epistemology, vol. 23. Translated by A. Sunier. Boston: D. Reidel Publishing Co. Describes research on pre-operational reasoning, called 'constituting functions', in young children. Shows howthe one-way operations form categories and 'morphisms' in early thought.

1967. Piaget, Jean, and Inhelder, Bärbel. ***The Child's Conception of Space.*** Translated by F.J. Langdon and J.L. Lunzer. W.W. Norton. Another example of how activity develops to construct a concept of reality, the spatial object. Shows the development of concrete operations of classification and seriation as they appear as spatial operations to form concepts of space.

1974. _____. ***The Child's Construction of Quantities.*** Translated by Arnold J. Pomerans. Basic Books. A classic introductory research text showing the conservation phenomena produced by the development of concrete operations, in this case, in the concepts of quantity, weight, volume, and density. Provides a clear verification of the fundamental importance of the formation of mental operations into systems as the method for constituting a concept.

1975. _____. ***The Origin of the Idea of Chance in Children.*** Translated by Lowell Leake, Jr., Paul Burrell, and Harold D. Fishbein. W W Norton. Shows how students naturally develop understanding and distinctions between chance events and those having underlying causal relationships. Covers the development of chance, probability, correlations, combinations, and permutations.

1960. Piaget, Jean; Inhelder, Bärbel; and Szeminska, Alina. ***The Child's Conception of Geometry.*** Translated by E.A. Lunzer. Basic Books. An in-depth follow-on study to the research on the development of spatial understanding. A rich source of information regarding basic concepts of points, lines, planes, coordinate systems, measurements, angles, and so forth. Perhaps in no other area does Piaget have so direct yet so under-utilized a contribution to make to education as in the area of geometry and spatial reasoning.

1952. Piaget, Jean, and Szeminska, Alina. ***The Child's Conception of Number.*** Translated by Caleb Gattegno and Frances Mary Hodgson. Humanities Press. Another classic text often referenced but poorly understood. Shows how the fundamental basis of number rests in the development of a qualitative system of logic which organizes both classification and seriation into number. Again, shows the fundamental importance of the activities and operations of thought in constituting the elements and numbers and not the reverse.

## Developmental Psychology:

1967. Piaget, Jean. ***Six Psychological Studies.*** Translated by David Elkind and Anita Tenzer. New York: Random House. Covers general aspects of mental development, structures, genetic epistemology, psychology of intelligence, and language. Of central concern in a theory of development is the concept of equilibrium which is presented in chapter IV.

*1960. _____. ***Psychology of Intelligence.*** Translated by Malcom Piercy and Daniel Ellis Berlyne. Totowa, New Jersey: Littlefield, Adams and Co. Perhaps one of the best introductory texts to Piaget's theories. Uses dated language but addresses fundamental problems and theories being debated today. Discusses the importance and theory of systems and the differences between behavior, intuition, and rational thought. 'Must' reading.

*1969. Piaget, Jean, and Inhelder, Bärbel. ***Psychology of the Child.*** Translated by Helen Weaver. New York: Basic Books. Presents a simply written synthesis and summary of the work of Piaget and Inhelder. Discusses the development of sensory motor activity up through formal thought and how the development of activity affects perception, language functions, and affectivity.

## Genetic Epistemology:

1980b. Piaget, Jean. ***Adaptation and Intelligence: Organic Selection and Phenocopy.*** Translated by Stewart Eames. Chicago: University of Chicago Press. A short, follow-on text to *Biology and Knowledge* to dispel common misinterpretations. Provides a clear explication of the parallel theory of biological evolution which corresponds to equilibration theory of knowledge. Refutes both Lamarkianism and Darwinism in both biology and their equivalents in psychology. Piaget is neither a maturationist nor an empiricist.

*1971a. _____. ***Biology and Knowledge: An Essay on the Relations Between Organic Regulations and Cognitive Processes.*** Translated by Beatrix Walsh. Chicago: University of Chicago Press. Heavy duty text which develops the thesis that knowledge is simply an advanced form of the adaptation of human activity to external reality. Knowledge is a form of biological adaptation subject to the very same mechanism of development as biological evolution which also is an equilibration of activity between the structures of the organism and the environment. Behavior and activity are the sources of evolution, not chance mutation and selection. Life is essentially autoregulation.

*1973a. _____. ***Child and Reality: Problems of Genetic Psychology.*** Translated by Arnold Rosin. New York: Grossman. Discusses common problems of developmental psychology and the growth of knowledge.

*1970b. _____. ***Genetic Epistemology.*** Translated by Eleanor Duckworth. Columbia University Press. Short and very simply written overview of genetic epistemology without technical language (actually a series of four lectures delivered in the U.S.) explaining the fundamental problem of the origins of knowledge using examples in the areas of mathematics, space, time, language.

1970c. _____. "Piaget's Theory." Translated by Guy Cellerier and Jonas Langer. In ***Carmichael's Manual of Child Psychology,*** Vol. 1, 3rd ed., pp. 703-32. Edited by Paul H. Mussen. John Wiley & Sons, 1970c. Excellent, technical summary laying out the fundamental concepts of Piaget's theory of development in his own words. Addresses the relation between the subject and object, assimilation and accommodation, stages, relations between development and learning, the operative and figurative aspects, factors of development, equilibration and cognitive structures, and the logico-mathematical aspects of structures.

*1970d. _____. ***Place of the Sciences of Man in the System of Sciences.*** New York: Harper and Row; Harper Torchbooks for UNESCO. A short, insightful text of considerable use to science teachers for its definitions of science and the various disciplines, and principles, mechanisms, and stages of scientific progress.

*1972. _____. ***Principles of Genetic Epistemology.*** Translated by Wolfe Mays. New York: Basic Books. Another short, excellent text providing an overview. Foundational text for anyone wanting a clear understanding of Piaget's science of knowledge.

*1971c. _____. ***Psychology and Epistemology.*** Translated by Arnold Rosin. New York: Grossman. Shows how developmental psychology provides a tool to scientifically answer questions of epistemology. Clarifies the fundamental problem of the source of knowledge and shows specific instances of how the problem is researched. Distinguishes between the proper domains and definitions of science and philosophy.

1988. Piaget, Jean, and Garcia, Rolando. ***Psychogenesis and the History of Science.*** Translated by Helga Feider. Columbia University Press. The result of the studies in causality. Shows that the stages in the development of students' understanding of various causal explanations recapitulates in structural form the stages in the history of science and algebra. Very important model for science education methods.

**STRUCTURES (SYSTEMS):**

*1957. Piaget, Jean. ***Logic and Psychology.*** Translated by Wolfe Mays and Frederick Whitehead. New York: Basic Books. A very short, concise text providing a simplified introduction to the technical points of various psycho-logics which are used to describe the mental operations of thought.

*1960. _____. ***Psychology of Intelligence.*** Translated by Malcom Piercy and Daniel Ellis Berlyne. Totowa, New Jersey: Littlefield, Adams and Co. Written around the time of the development of the theory of groupings, this text provides a less technical explanation of groupings and structures than found in later texts. See chapter II for an excellent introduction to cognitive structures.

*1970e. _____. ***Structuralism.*** Translated by Chaninah Maschler. New York: Basic Books. It is hard for Americans to appreciate the great interest in and importance of structuralism in Europe. This text shows the fundamental importance of structuralism as a method in the study of all human productions, social, mathematical, scientific, linguistics, etc. In chapter 1 it provides three fundamental distinguishing characteristics of all structures.

**EDUCATION:**

*1970f. _____. ***Science of Education and the Psychology of the Child.*** Translated by Derek Coltman. New York: Grossman Publishers. Reviews the state of education and shows why students' activity must be the philosophic basis for education.

*1973b. _____. ***To Understand is to Invent: The Future of Education.*** Translated by George-Anne Roberts. Viking Press for UNESCO. Lays out an ethics for education as part of UNESCO's Universal Declaration of Human Rights. A second part concerns the structural foundations of education.

**OTHER WORKS:**

1971b. _____. ***Insights and Illusions of Philosophy.*** Translated by Wolfe Mays. New York: Meridian. Lays out the proper role of philosophy as opposed to science. Philosophy is a wisdom which does not prescribe limits or methods to science nor is philosophy a 'higher' form of knowledge. Philosophy is a coordination of values.

1981. _____. ***Intelligence and Affectivity: Their Relationship During Child Development.*** Annual Reviews Monograph, ed. Mark R. Rosenzweig. Translated by T. A. Brown and C. E. Kaegi. Palo Alto, Cal.: Annual Reviews. A short text compiled from Piaget's lectures on the development and role of the affective component in all activity and knowledge. Provides the stages of affective development.

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